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Energy conservation and emissions reduction in China—Progress and prospective

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ABSTRACT

Energy conservation (EC) has been taken as basic state policy in China for more than 20 years and China achieves 3.9% annual energy saving from 1980 to 2005. In 2006 China Central Government firstly set up a binding target of reducing GDP energy intensity by 20% in its 11th Five-Year-Plan (FYP). At the end of 2010, 19.1% reduction in energy intensity has been achieved, which is 95% of the target and means 608 million tons stand coal equivalence (sce) saved, 1510 million tons CO_2 emission reduced, 300 billion RMB¥ saving in energy bill and vast saving in infrastructure investment. This paper is systematical review and prospective analysis on energy policy issue in China. Review on policy evolution and progress of EC and Emission Reduction (ER) in China during the 11th FYP periods is presented in detail. Outlook of energy demand and supply into 2050 is presented and the roadmap to realize sustainable energy development is drafted to set the framing constraints for China's energy policy options. Rationality and feasibility analysis on newly formulated 12th FYP EC and ER target is also addressed. Then lessons from the 11th FYP periods are drawn and factors underlying and limiting the policy formulation and implementation are discussed in details to probe the policy predicament and solutions. Finally policy suggestions are proposed for long-term successful implementation of EC and ER in China.

Contents

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1. Introduction

Since launching its Reform and Opening-up policy in 1978, China has achieved a miracle of 9.8% annual GDP growth for more than consecutive three decades. However, the miracle is achieved at high environment and ecology cost with low energy and resource efficiency, which has been notoriously criticized for years. To address the persistent pressure on resource and environment, China Government officially took sustainable development as the basic state policy in the 16th Conference of Communist Party of China (CPC) in 2002. Then in the 17th conference of CPC, sustainable development was officially taken as one of the cores of "*scientific development perspective*", China's current summit development tenet. In fact, energy efficiency has long been on the policy agenda in China. With continuous efforts, GDP energy intensity decreased by 50% from 1980 to 1995, which has been extensively probed in literature [1–5]. Then in the 9th Five-Year-Plan (FYP), annual saving energy by 5% and reducing main pollutants of SO_2 and COD was proposed by Central Government, which is the first energy saving and emission reducing goal among developing countries. Because of the massive economic restructuring, efficiency enhancing in energy intensive industries and the slow-down of GDP growth due to Asian Crisis, the actual performance is 6.1% and pollutant of SO_2 and COD is cut down significantly. Nonetheless, according to many experts China's experience during the periods was an exception. As argued by Lin et al. [6], in the early stage of economic development, industrialization and urbanization tend to lead to extensive infrastructure and housing development, which will in turn consume much energy resource. Accordingly, as far as China follows the "old way" that industrialized countries have experienced, energy intensity will reverse. Unfortunately, this is what happened in China during the 10th FYP periods. In 2001 inspired by the great success of the past 5 years, another EC target of 10% is set for the10th FYP. However, during the periods, China economy recovered from Asian Crisis and speeded up. Increased energy consumption incurred by the shift of output structure toward heavy industry, as well as the slow-down of efficiency enhancement in energy-intensive sectors ultimately resulted in a 7.5% rise in energy intensity in 2005 [7,8] (see Fig. 1 for energy, carbon and electricity intensity in China). Reported on energy consumption and carbon emission elasticity, from 2002 to 2004, elasticity greater than one for consecutive 3 years was witnessed. When examining electricity, because of rapid electrification during the periods, electricity consumption elasticity was greater than one from 1999 to 2007. As a result, a consecutive increase of GDP electricity intensity was witnessed from 1999 to 2006 (Figs. 1 and 2). Of course whether or not increase in electrification level will lead to decrease in energy intensity is an intriguing and important issue, which is beyond the scope of this paper.

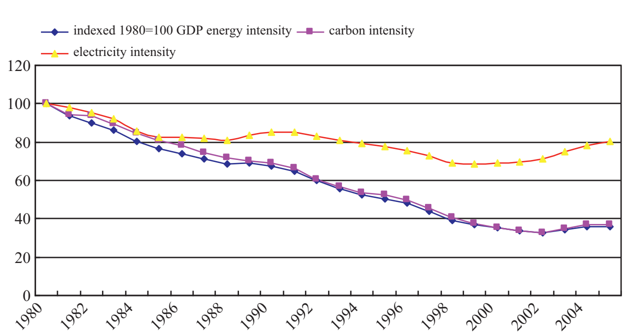

Fig. 1. China's energy, carbon and electricity GDP intensity index from 1980 to 2005.

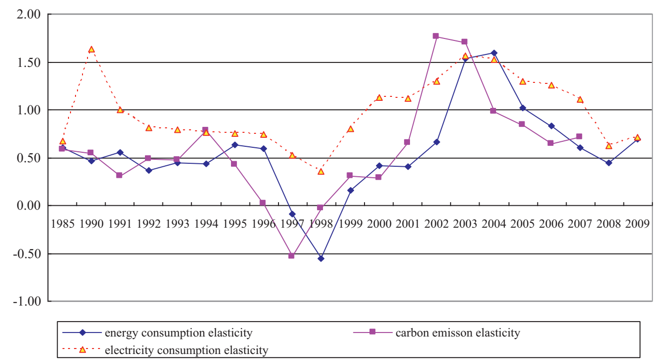

Fig. 2. Energy-electricity consumption and carbon emission elasticity in China. *Source*: Ref. [25] for carbon data and Refs. [28,29] for other data.

Though China set EC target for both its 9th and 10th FYP periods, it was in the 11th FYP that firstly a binding target, reducing GDP energy intensity by 20%, main pollutant of SO_2 and COD by 10% in 2010 as of 2005 was set. In China, targets included in the FYP are those viewed as the most important by Central Government, who should be responsible to achieve them. As noted by Lin et al. [6], this move signals a major shift in China's strategic thinking about its long-term economic and energy development and provides further evidence that the China government is serious in its call for a new "*scientific development perspective*". The target itself is of important policy implication considering its potential contribution to global efforts fighting against GHG emissions and thus catches intensive attention in literature. In an earlier study carried out by Lin et al. [6] at 2007, policy scenarios are provided to study the feasibility of target and it is concluded that with efficiency improvements in the industrial and buildings sectors, as well as structural changes in the economy, together with vigorous implementation of a host of policies, the 20% energy-intensity reduction target is feasible. In another study by Yang [9], the potential of different sectors or measurements to energy intensity reduction is appraised and seven policy actions and measures are proposed for achieving the target. In a later study by Zhou et al. [10], a comprehensive assessment of the policies and programs taken by China government is provided.

By the end of 2009, just before UN Copenhagen Climate Change Conference, China announced another ambitious target, promising to reduce GDP carbon intensity by 40–45% than that of 2005 and increase the share of non-fossil energy in primary energy to 15% by 2020 [11,12]. This move is another serious promise that China will pursue its way on EC and ER. To implement this target and extend the policy during the 11th FYP periods, 17% reduction in GDP carbon intensity (equaling 16% reduction in energy intensity), 8–10% reduction in main pollutant and increase the ratio of non-fossil over primary energy to 11.4% are included in the newly formulated 12th FYP, among which the targets of carbon intensity and the non-fossil ratio are firstly appeared in China's highest level planning.

Considering the target's potential impact on China as well the world as a whole, the issues of concern are naturally centered on the followings: What did China Government actually do during the 11th FYP periods? What progress and achievement has China made during the past 5 years? What are the problems and obstacles

deserving investigation? Is the newly proposed EC and ER target for the 12th FYP periods reasonable and in accordance with 2020 vision? Finally what does China Government need to adjust in institution setting and policy system to deliver the target? Though the focus of those earlier literatures [6,9,10] after the announcement of the 11th FYP target is on feasibility appraisal and policy advice, at the turning point between 11th and 12th FYP periods, the interest of this paper is to systematically review on the policy evolution during the past 5 years, to evaluate the actual effects of these policies and summarize experiences and lessons. The rationality and feasibility of the 12th FYP target under the long term perspective of energy development in China will also be addressed. As the most populous and biggest developing country with largest carbon emissions in the world, China's experiences are of reference value globally.

The remainder of the paper is organized as follows. Section 2 reviews on China's EC and related policy formulation during the last 5 years. Section 3 appraises the achievement of 11th FYP EC target in different perspectives. Section 4 gives a long-term prospective of China's energy sector into 2050 and then addresses on the rationality and feasibility of China's EC and ER target for its 12th FYP periods. Section 5 will draw out some lessons from policy formulation and implementation in 11th FYP periods and finally Section 6 is policy outlook.

2. Progress on EC and ER institutionalization in China during the 11th FYP

In 2003, primary energy consumption increased by 15%, significantly higher than GDP growth at the same year and the annual average of 3.6% from 1991 to 2002. It became clear to China Government that the rapid growth of energy demand will present serious problems and thus would not be sustainable. Then in 2004, primary energy consumption increased by 16%, thus dooming the 10th FYP target. As a quick response to this unfavorable trend, China released the *Medium and Long-Term Plan for Energy Conservation* in 2004 [13]. The plan sets out specific EC targets for the manufacturing industry, transportation and buildings sectors and works out many operational measures and thus sets the keynote of policy evolution.

The focus of the plan is on "top ten priorities" and "Ten-Key Projects." The "top ten priorities" are: (1) Establish a system for monitoring, evaluating, and public reporting of energy intensity; (2) Eliminate and/or reduce production from inefficient industrial processes, technologies and facilities, reduce production from inefficient industrial facilities, encourage high technology industry, and shift production away from energy-intensive industries; (3) Implement "Ten-Key Projects"; (4) Implement "1000 enterprises energy conservation program"; (5) Strengthen existing and create new financial incentives for energy-efficiency, including preferential tax policies on energy conservation; (6) Strengthen Energy Conservation Laws, regulations and standards (e.g., mandatory appliance labeling; more aggressive enforcement of building energy codes); (7) Strengthen government programs to gather energy data; (8) Establish a National Energy Conservation Center; (9) Promote energy-efficiency and conservation in government agencies; (10) Expand media programs; strengthen training of energy conservation professionals. The Ten-Key Projects are focused on reducing energy use in industry and buildings and include: (1) renovation of coal-fired industrial boilers using 70 million tons of coal (50 million tons sce, Mtce) annually; (2) regional cogeneration projects (saving 35 Mtce annually); (3) waste heat and pressure utilization (1.35 Mtce/year); (4) oil conservation and substitution saving 38 million tons of oil (54.3 Mtce/year); (5) motor system energy-efficiency saving 20 TWh (2.46 Mtce/year); (6) energy systems optimization; (7) energy-efficiency and conservation in buildings saving 100 Mtce/year; (8) energy-efficient lighting saving 29 TWh (3.56 Mtce/year); (9) government procurement of energy-efficiency products; and (10) monitoring and evaluation systems. The expected impact of these ten projects is more 250 Mtce in the 11th FYP period [13].

In the plan, both macro and micro energy conservation targets are set. On macro scope, the GDP energy intensity should decrease by 2.2% annually until 2010, amounting to energy conservation capacity of 400 Mtce and decrease by 3% until 2020, amounting to energy conservation capacity of 1.4 Btce. On micro scope, in 2010, the unit energy consumption index of major products (measured in workload) should reach the international advanced level during 90th of 20 century and in 2020 reach or approach international level (see Tables 1 and 2).

In the end of 2005, in recognition of the unsustainable pace of energy demand growth and its associated adverse consequences, the Politburo of the Communist Party issued a communiqué in which it called on the nation to reduce energy intensity by 20% in 5 years, which is regarded as the signal of strong determination of the Party and Central Government. Then the 11th FYP was approved by the 5th Plenary Session of the 16th CPC. It sets up a binding energy conservation target for local governments and key central government departments, requiring all government divisions at different levels to ensure the achievement of the target. The plan also establishes specific efficiency targets for power generation, selected industrial processes, appliances and transport, which are mainly the restates of the targets in the *Medium and Long-Term Plan for Energy Conservation*. Then in late 2006, the State Council approved and distributed a scheme disaggregating the 11th FYP's national energy-saving target into energy-saving targets for each province and further required local governments to disaggregate provincial targets to cities and counties [10,14]. Under that requirement, a hierarchical administration system for EC ranging from nation to province and city level is constructed during the 11th FYP periods. Then from legislation by National People's Congress (NPC) to regulations by State Council and its ministries, from administrative measures in command and control to technology standards, finance and price policy, from comprehensive measures to sectoral measures, a host body of EC policies is put in place. Table 3 summarizes the policy formulation during the periods. Legislation, government regulation, technology standard, finance and tax, as well as price policy to implement EC are listed with their main concerns. It is worth noticing that in practice, the actual boundary between different kinds of policy is not clear cut. For example, phase-out of low efficient production capacity is in the class of technology standard. But the actual implementation of it is by government regulation and supported by fiscal policy. Another case is the reform on petroleum products taxes and dues. Though largely being tax policy, its implementation actually anchors the domestic petroleum price with the international price and in effect plays very significant role as price policy. Currently in China, though the price for coal and petroleum is already determined by market (or semi-market) mechanism in a large extent, electricity price is still under strict government control. Generally speaking, during the 11th FYP periods, the policy in the fashion of command-and-control plays the most important part.

The institutionalization process, though seemly successful, is anything but smooth and ordered. Except the revision of energy conservation law and State Council Decision on strengthening energy conservation, the only practical policy issued in 2006 is the 1000 enterprises energy conservation program. As is shown in Table 4, the rather sluggish beginning for 2006 (2.74% realized vs. target of 4.4%) warned the government of the difficulty of EC, and since 2007, extensive policies were issued and implemented until the end of 2008, the governments of all level focused on response to the unexpected Global Financial Crisis and package of vast investment was made to stimulate the economy. Then in June of 2010,

Table 1
Planning of unit energy consumption index of major products (workload).

	Unit	2000	2005	2010	2020
Coal consumption of thermal power	Grams of standard coal/kilowatts	392	377	360	320
Comprehensive energy consumption of each ton of steel	Kilograms of standard coal/ton	906	760	730	700
Comparative energy consumption of each ton of steel	Kilograms of standard coal/ton	784	700	685	640
Comprehensive energy consumption of 10 kinds of non-ferrous metal	Tons of standard coal/ton	4.809	4.665	4.595	4.45
Comprehensive energy consumption of aluminum	Tons of standard coal/ton	9.923	9.595	9.471	9.22
Comprehensive energy consumption of copper	Tons of standard coal/ton	4.707	4.388	4.256	4.000
Energy consumption of unit energy factor of oil refining	Kilograms of standard oil/tons factor	14	13	12	10
Comprehensive energy consumption of ethylene	Kilograms of standard oil/ton	848	700	650	600
Comprehensive energy consumption of large-scale synthetic ammonia	Kilograms of standard coal/ton	1273	1210	1140	1000
Comprehensive energy consumption of caustic soda	Kilograms of standard coal/ton	1553	1503	1400	1300
Comprehensive energy consumption of cement	Kilograms of standard coal/ton	181	159	148	129
Comprehensive energy of building ceramics	Kilograms of standard coal/cubic meter	10.04	9.9	9.2	7.2
Comprehensive energy consumption of railway transport	Tons of standard coal/million tons converted to miles	10.41	9.65	9.40	9.00

Source: Refs. [13,32].

finding that energy intensity increase merely rather than decrease for the first half of 2010 and very likely that a large portion of the target being unaccomplished at the deadline, the Central Government then rushed to throw out strictest restructuring policy with strong administrative means.

Eleventh FYP for Energy Development as well as *Medium and Long Term Plan for Renewable Energy Development* [34] were released in 2007. The energy efficiency target for the 11th FYP periods is restated in the plan. In the renewable energy plan, an ambitious renewable energy development target (accounting for about 10% of the total energy consumption by 2010 and 15% by 2020) is set.

Totally, with strong determination and vast input, China has made conspicuous progress in EC institutionalization. Law is formulated, medium-and-long-term plan drafted, comprehensive program worked out and billions of fund input for capability building, which lays sound foundation for the accomplishment of the target. In the next section the progress during the 11th FYP will be discussed in three perspectives: national level, provincial level and in some key fields.

3. Achievements on EC and ER in China during the 11th FYP

3.1. National level

According to 2011 Statistical Bulletin (NBS 2011) and government work report, China's GDP energy intensity reduced by 19.1% during the 11th FYP periods, quite close to the target of 20%. Regarding the main pollutant, COD reduced by 12.45% and SO_2 reduced by 14.29%, far beyond the target of 10%. According to calculation in Table 4, measured in chain relative ratio, a total of 608 Mtce primary energy is saved, which implies reduction of CO_2 emission in 1510 million tons and saving of energy bill for the whole society amounting to 370 Billion RMB¥. The indirect benefits, though difficult to calculate, also deserve admiration. About 2 trillion direct investments in energy production capacity (including coal, oil extraction and power generation) are avoided, let alone the vast investment in transportation, environment management, pollution abatement, the direct and indirect expenditure for safeguarding international oil import, and the saved expenditure on health care. The environmental benefits of energy conservation in China are also remarkable. Taking year 2009 for example, the percentage of cities with air quality better than Class 2 for more than 292 days increased from 69.5% in 2005 to 95.7%, the percent of surface water national control section in Class 5 or worse decreased from 26.1% in 2005 to 20.6% while the percent of national control section of the seven major rivers better than Class 3 rise from 41% to 57%.

The low carbonization in manufacturing sector is remarkable. According to estimation, from 2005 to 2008, the value added of manufacturing sector decreased by 4.6% annually, which is faster than GDP energy intensity decrease (4%) and accounts for 58.7% of total energy saving for the corresponding periods. Meanwhile, the CO_2 emission per 10,000 RMB¥ value added in manufacturing sector decreased from 5.08 to 4.30 tons, with an annual reduction of 5.4% and accounts for 65.7% of total CO_2 reduction. In addition, the low carbonization in agriculture sector, the only sector achieving the absolute decrease in energy consumption also deserves attention. The energy consumption of agriculture sector decreased by 2.2% in 2008 as of 2005 while the energy intensity in this sector decreased by 15%.

The primary energy consumption grows with an annual rate of 9.6% to 3.25 Btce in 2010, significant higher than the planed control target of 2.7 Btce. Without proper control, the balance between supply and demand will soon become unmanageable in China. On the other hand in 2010 the non-fossil energy (hydropower, nuclear and renewable energy) accounts for 8.3% of primary energy consumption, slightly higher than the planed target of 8.1%, implying

Table 2
Planning of energy efficiency indicators of major energy-consuming equipment.

	Unit	2000	2010
Coal-fired industrial boilers (running)	%	65	70–80
Medium- and small-sized motors (design)	%	87	90–92
Blower (design)	%	70–80	80–85
Pump (design)	%	75–80	83–87
Gas compressor (energy efficiency ratio)	%	75	80–84
Room air conditioner		2.4	3.2–4
Refrigerator (energy efficiency indicators)	%	80	62–50
Household gas stove (thermal efficiency)	%	55	60–65
Household gas heater (thermal efficiency)	%	30	90–95
Average fuel economy of automobiles	L/100 km	9.5	8.2–6.7

Source: Refs. [13,32].

Table 3
Energy conservation policy at national level during 11th FYP in China.

Policy type	Policy and its concerns	Constitutor and effective date
Legislation	*Renewable Energy Law:* formulates provisions on resource investigation and planning, industry guide and technology support, popularization and application, price management and cost allocation, economic incentive and supervision measures related to renewable energy development; especially requires that power grid corporations sign grid accession contract with approved or registered renewable generation corporations and purchase renewable power generation at feed-in price	[26]
	Revision of *Energy Conservation Law:* (1) highlights the strategic importance of energy conservation; (2) broadens government authority for energy-efficiency to buildings, transportation and public organizations; (3) perfects the energy efficiency standard and regulation system; (4) identifies the government department responsible for implementing energy efficiency target; (5) provides a legal basis for the creation of special fund and incentive policies for energy-efficiency; (6) stipulates the legal liability for private and public entities when violating energy-efficiency law and regulations	[42]
Government regulation (command and control)	*Some regulations on facilitating industrial structure adjustment:* takes energy efficiency and environment protection as one of the important criteria for guidance catalogue classification	[36–38]
	Decision on Strengthening Energy Conservation: restructures output to conserve energy; restricts new high energy-consuming projects and sets mandatory thresholds of energy consumption for new project approval; identifies NDRC and its provincial counterparts as accountable for EC targets; requires the inclusion of EC target in the comprehensive performance system of the local government	[33,43]
	Implementation Program of Ten-Key Projects at 11th FYP: identifies the specific project domain, assignment and supporting measures	[44]
	Energy conservation special program in 1000 Enterprises: implements energy conservation in 998 enterprises with annual energy consumption more than 180 thousand tons sce and realizes a total of 100 Mtce energy conservation	[31]
	Comprehensive Work Plan for Energy Conservation: strengthens the administration of the already-adopted policies; requires setting up accountability and "one-vote veto" system for regional governments; implements various measures addressing EC	[46]
	State Council's Schedule on Energy Conservation: phases out 13 GW small-scale generation units, 50 million tons cement, 6 million tons steel, 14 million tons iron, 0.15 million tons electrolytic aluminum, 0.8 million tons ferroalloy, 15 millions tons coke, 500 thousand tons calcium carbide, 6 million boxes of plate glass and 1 million tons paper and pulp production capacity	[46]
Technology standards	*Circular on Further Strengthening Phase-out of Backward Production Capacity:* reiterates to phase out small scale generation units by 50 GW, small coal mine by 200 million tons, coke plant with carbonization room height less than 4.3 m^2 and irons and calcium carbide plant with furnace less than 6300 KVA in the end of 2010	[39,40]
	Phase-out of small-scale thermal generation units and inefficient energy intensive production line in steel, cement and other sectors: shuts down 50 GW small-scale thermal units, 150 million tons iron and steel capacity, 300 million cement capacity during 11th FYP	[36,39]
	Energy-efficiency labeling: approves compulsory national standards of energy consumption limits for 22 high energy-consumption products and compulsory energy efficiency standards for 11 end-using products	
Financial and tax policy	*Special fund*: provides 210B RMB¥ investment fund in energy conservation, emission reduction and ecology protection	[46]
	Revised export tax rebates: reduces export tax rebates for many low-value-added but high energy-consuming products, from 11% to 8% for steel, from 13% to 8% for cement and 13% or 11% for glass and from 13% to 5%	[48]
	Revised vehicle consumption tax: puts a higher tax burden on larger, energy-inefficient vehicles	[49]
	Reform on petroleum products taxes and dues: raises the consumption tax for per liter gasoline from 0.2 RMB¥ to 1 RMB¥, and for diesel from 0.1 RMB¥ to 0.8 RMB¥; reforms the petroleum products pricing mechanism based on international oil price	[47]
	11th FYP City Green Lighting Project Development Outline: initiates fiscal subsidy to popularize high efficient lighting products and provides 50% and 30% subsidy for household and bulk users respectively	[18]
Price policy	*Enforcement of differentiated electricity price*: surcharges 0.05 RMB¥ and 0.20 RMB¥ per kWh for enterprises in the "restricted" and "eliminated" categories based on energy efficiency	[30,35]

Note: Sourced from various resources and complied by the authors.

Table 4
Planned and actual GDP energy intensity and energy conservation during the 11th FYP.

	2005	2006	2007	2008	2009	2010	2006–2010
Planned GDP (2005 price trillion)	18.2	19.57	21.03	22.61	24.31	26.1	–
Planned GDP energy intensity (in tons sce per 10 thousand ¥RMB 4.4% decrease annually)	1.276	1.22	1.166	1.115	1.066	1.021	–
Planned energy conservation (million tons sce)	–	110	113	116	119	117	550
Actual GDP (2005 price trillion)	18.2	20.31	22.95	25.02	27.29	30.1	–
Actual GDP energy intensity	1.276	1.241	1.179	1.118	1.077	1.034	–
Actual energy conservation	–	71	142	153	112	130	608

Note: 2005–2010 actual GDP energy intensity data are sourced from NBS (2006–2011) statistic bulletin [15,29].

that energy supply structure better up during the past 5 years with China's great effort developing renewable energy.

3.2. Provincial level

Progress on EC and ER is also witnessed in provincial level. In late 2006, the State Council decomposed the 11th FYP's national energy-saving target into energy-saving targets for each province. The reduction percent for Yunan, Tibet, Qinghai, Hainan, Guangxi, Guangdong and Fujian based on their 2005 level are less than 20%; the counterparts for Henan, Shandong, Shanxi, Inner Mongolia and Jilin are more than 20%; the targets for all the other provinces are the same as national target of 20%. According to the statistic bulletin by NBS 2007–2010 (shown in Fig. 3), at the end of 2009, Beijing and Tianjing have fully achieved their targets; 5 provinces (Qinghai, Guizhou, Sichuan, Inner Mongolia and Shanxi) have achieved 60–80% of theirs targets; only 3 provinces (Xinjiang, Hainan and Jilin) have achieved less than 60% of their targets; all the other 20 provinces have achieved more than 80% of their targets [15]. Though the data for 2010 is not available at the time, it is quite reasonable to infer that most of the provinces could realize their target given the published national data.

In China, even though the State Council has seemly infinite power over economic affairs, the willingness of provincial governments to implement the policy plays even more important role. The interactions between the central and local governments constitute the institutional environment of policy-making for local governments, which then exerts significant influence on local governments. In terms of energy efficiency, the order and initiative of the Central Government is an important reason for the local governments' actions. Provincial governments obtain political powers and substantial financial resources from the Central Government. This is an important reason for energy efficiency enhancement and institution building in local governments. In essence, this is an administrative response rather than the enhancement of awareness and consciousness of local movements of climate change like California and northeastern states of the US [16]. At the level of the Central Government, the *Comprehensive Program of Energy Conservation and Emission Reduction* states that in order to enhance the leadership on EC and ER, the Sate Council will set up a leading group and requires local governments to enhance leadership in their jurisdictions. Therefore it can be found that the countermeasures of local governments for dealing with energy efficiency are most made in response to the demonstration effect of the relevant policies of the Central Government and at the request of the Central Government. For instance, Hainan Province released its Comprehensive Work Program of Energy Conservation and Emission Reduction "to follow the spirit of the Comprehensive Program of Energy Conservation and Emission Reduction by State Council". Shandong, Heilongjiang and Chongqing, etc. released such program also. In addition to the comprehensive programs mentioned as above, departments of some local governments issued energy saving and emission reduction policies in response to the policies by the State Council and its ministries. For example, in March 2008, Anhui Province promulgated the *Implementation Program of Energy Conservation and Emission Reduction* during the 11th Five-Year Plan in construction industry. Provincial governments also established scoring system to evaluate the municipal governments for EC responsibility. It is this kind of forced "top-down" administration system that successfully manages to carry out the energy efficiency enhancement during the 11th FYP periods. As will be discussed in Section 5, because of the deficiency in government incentive mechanism design, the efficacy of the system is subject to question and will be gradually disabled since 2010 with Central Government's unprecedented endeavor to get the final test passed at the deadline.

3.3. Progress in key fields

3.3.1. Renewable energy development

With the release of *Renewable Energy Law*, renewable energy has experienced rapid development in China. According to Table 5, hydropower has increased from 116.52 GW in 2005 to 213.74 GW in 2010; nuclear power has increased from 6.85 GW to 10.82 GW while at the end of 2009 there was 23.05 GW still under construction. The growth of wind power is the most spectacular: the installed capacity connected with power grid has increased from 1.06 GW in 2005 to 31.07 GW, if including the isolated capacity in the end of 2010 the total wind power in China reached 44.7 GW, while the officially planed number is 5 GW. The ratio of thermal power in total generation capacity has decreased from 75.1% in 2005 to 74.5% in 2009. With the rapid development of non-fossil energy, the ratio of thermal power will further decrease in the future.

3.3.2. 1000 enterprises energy conservation program

Energy conservation of 1000 enterprises has made smooth progress since the release of the program in April of 2006. According to the bulletin by [45], the energy efficiency measured in unit product has made obvious progress compared with 2006 [15]. A total of 20 Mtce was saved in 2006, among which, 92% was from 4 industries of steel, chemical product, electric power, oil refinery and chemical. In 2008, 886 enterprises among 922 enterprises which participated in the evaluation in 2008 (some enterprises among 953 enterprises participating in the evaluation of 2007 did not participate in the evaluation in 2008 due to merger, bankruptcy, closedown or other reasons) realized yearly energy conservation targets, accounting for 96.1% of all enterprises. Only 36 enterprises or 3.9%, failed to realize the yearly target. In 2008 alone, a total of 35.72 Mtce was saved. In the end of 2008, 1000 enterprises program saved accumulative total of 106.2 Mtce, which is 106.2% of the goal during the 11th FYP and thus realizes the target in advance [17]. Table 6 presents the unit energy consumption index of major products in the 1000 key enterprises at 2006.

3.3.3. Energy efficiency enhancement in energy intensive industries

The State Council declared to shut down 50 GW small-scale thermal generation units during the 11th FYP period. According to the statistics by NDRC, the realized numbers for 2006–2009 are as follows: 2006 3.14 GW, 2007 14.38 GW, 2008 16.69 GW and 2009 25.85 GW. In the end of 2010, a total of 72.1 GW of such small-scale units was phased out, which is 144% of the set target. According to estimation, the replacement of such small-scale units by more efficient units can save crude coal by 84 million tons annually and approximate reduction of 168 million CO_2 and 1.45 million SO_2 emission.

Phasing out of low efficient capacity in energy extensive industries also makes progress. For steel industry, the task for 11th FYP periods is to phase out low efficient capacity in 100 million tons and at the end of 2009 81.7 million tons capacity had been phased out. For cement industry, the task is 250 million tons capacity and at the end of 2009 240 million had been phased out. Moreover, China Government has taken phasing-out low efficient capacity as one of the most important measures for energy efficiency and output restructuring in the long term. In 2010, the State Council worked out more ambitious goals for energy intensive industries. Considering the mission in the 12th FYP periods, for 2010 the target for steel industry has been raised from 18.3 to 25 million while cement industry has been raised from 10 to 50 million.

With the consistent efforts on restructuring, the manufacturing capacity in these key industries improved significantly and more high efficient large scale equipments were put into application. For

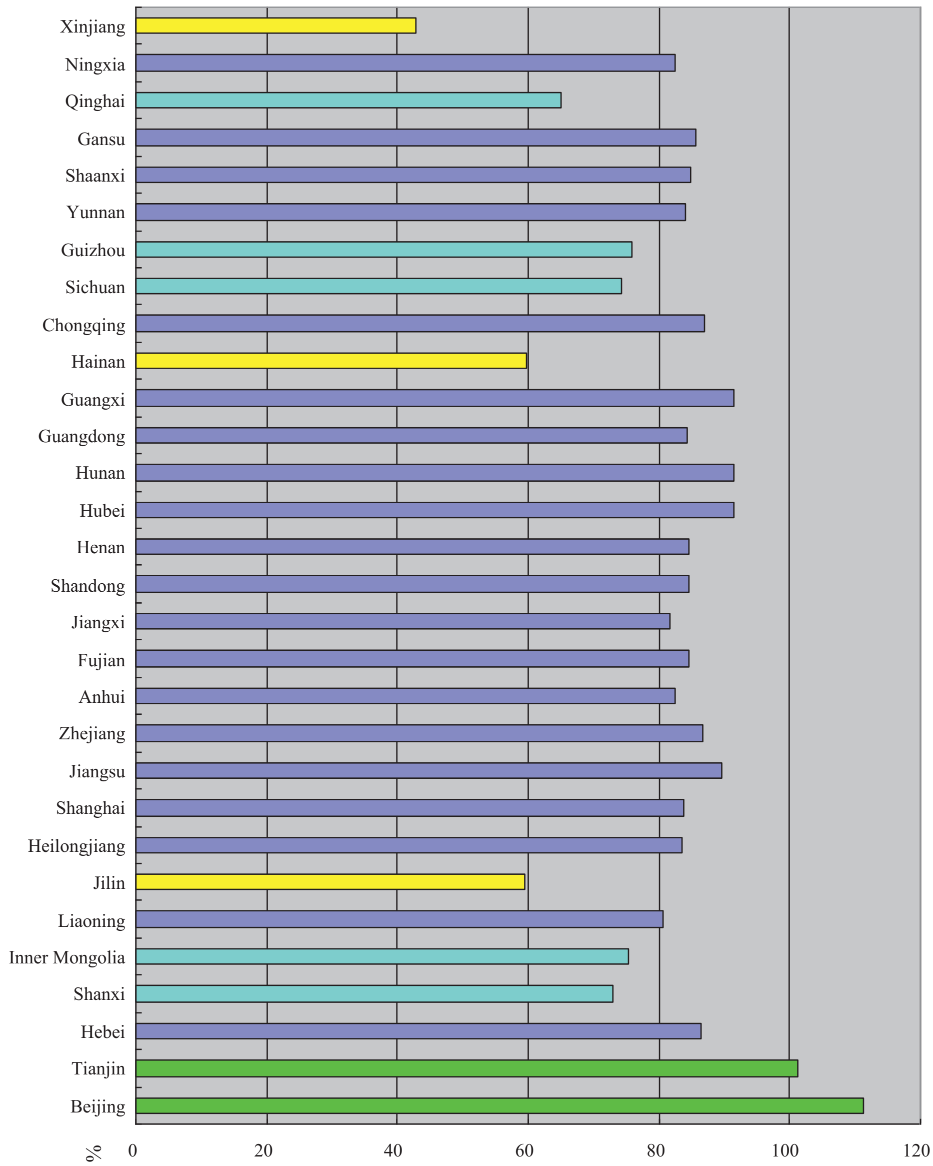

Fig. 3. Progress of energy conservation in various provinces during 2006–2009. *Note*: Tibetan data are not available, which are referred to Yunnan's data. All the data are sourced and calculated based on NBR [15].

example, the ratio of generation units above 300 MW in power sector rise from 47% in 2005 to 69% in 2009, the ratio of large blast furnace above 1000 m^3 in steel industry rise from 21% to 34% and the ratio of new type dry process capacity in cement industry rise from 56.4% to 72.2%. Technology progress in these industries results in the improvement of overall energy efficiency. For example, coal consumption for thermal power plant decreased from 370 to 340 g sce per kWh, the comprehensive energy consumption for producing per ton steel decreased from 694 to 615 kg sce, and the comprehensive energy consumption for cement decreased by 16.77%.

3.3.4. Energy efficiency labeling

In March of 2005, China launched mandatory energy information label (five categories of energy-efficiency), which is adapted from the European Union. Initially the label applied only to

Table 5
China's generation capacity from 2005 to 2010.

	Total generation capacity	Thermal power	Hydropower	Nuclear power	*Unit*: GW Wind power
2005	508.41	384.41	116.52	6.85	1.26 (1.06)
2006	622.10	484.05	128.57	6.96	2.56 (2.07)
2007	713.29	554.42	145.26	9.08	5.87 (4.20)
2008	792.53	601.32	171.52	9.08	12.02 (8.94)
2009	874.07	652.05	196.76	9.08	25.81 (16.18)
2010	962.19	706.63	213.4	10.82	44.73 (31.07)

In the last column data in bracket means grid-access wind power capacity.

Table 6
Unit product energy consumption in 1000 key enterprises.

Index	Unit	2006 average of 1000 enterprises	Decrease as of 2005 (%)	International advanced level	Domestic average level
Comprehensive energy consumption of each ton of steel	Kilograms of standard coal/ton	618	3.7	642	741
Comprehensive electricity consumption of each ton of crude coal	kWh/ton	41	0.3	56	–
Coal consumption of thermal power	Grams of standard coal/kilowatts	365	0.8	312	366
Comprehensive energy consumption of aluminum	Tons of standard coal/ton	14,733	0.8	14,100	14,795
Comprehensive energy consumption of large-scale synthetic ammonia	Kilograms of standard coal/ton	1453	3.5	990 (gas)1570 (coal)	1650
Comprehensive energy consumption of pure soda	Kilograms of standard coal/ton	422	0.2	345	461
Energy consumption of unit oil refining	Kilograms of standard oil/tons	77	4.2	73	104
Comprehensive energy consumption of ethylene	Kilograms of standard oil/tons	972	5.7	786	1003
Comprehensive energy consumption of cement	Kilograms of standard coal/ton	113	2.1	102	156
Comprehensive energy consumption per box plate glass	Kilograms of standard coal/box	16	4.0	15	22

refrigerators and room air conditioners, then in 2007 clothes washers and central air conditioners were added. From June of 2008, the Standardization Administration of the People's Republic of China approved compulsory national standards of energy consumption limits for 22 high energy-consumption products and compulsory energy efficiency standards for 11 end energy-using products, issued the catalogues of the third and the fourth batches of products with energy-efficiency labeling and the implementing rules. So products with energy-efficiency labeling have been successfully expanded to 15 kinds, which will have long term impact on household electricity consumption (see Table 7 for the details of energy efficiency labeling in China).

Table 7
Energy-efficiency labeling in China.

Batch no.	Product name	Data of implementation
1st batch	Household refrigerator Air conditioner in room	March 1, 2005
2nd batch	Electric washing machine Unitary air conditioner	March 1, 2007
3rd batch	Self-ballasted fluorescent lamp High-voltage sodium lamp Small, medium and large three-phase asynchronous electromotor Water chilling unit Domestic gas instantaneous water heater and gas fired heating and hot water combi-boiler	June 1, 2008
4th batch	Air conditioner in room, with controllable rotate speed Multi-connected air conditioning (heat pump) unit Water-storage electric water heater Domestic induction cooker Computer monitor Duplicating machine	March 1, 2009

Source: [17].

3.3.5. *Green lighting*

China has implemented green lighting ever since 1996 and achieved great success. In 2005, the volume of high efficient lighting bulb accounted for more than 50% of lighting bulb in China. In 2004, green lighting was taken as one of the Ten-Key energy saving projects in the *Medium and Long-Term Plan for Energy Conservation* [13]. Then in 2006, the Ministry of Construction released *11th FYP City Green Lighting Project Development Outline* requiring that on the base of 2005, 5% annual electricity saving should be realized in the 11th FYP and the ratio of high efficient bulb in application should be raised to 80% [18]. In 2008, China initiated fiscal subsidy policy to popularize high efficient lighting products and provides 50% and 30% subsidy for household and bulk users respectively. From 2008 to 2009, a total of 210 million pieces of high efficient bulbs were been sold propelled by fiscal subsidy. The effect is 8.8 billion kWh electricity saved and 8.8 million tons CO_2 reduced annually. In 2010, the target is to popularize 150 million pieces of high efficient bulbs and roadmap to phase out low efficient bulbs is currently in progress.

4. Perspective of China's energy sector into 2050

4.1. *Perspective of China's energy demand and supply into 2050*

During the past 30 years China did achieve great success on economy growth, but accumulated dozens of deep-rooted contradictions of imbalance, discordance and un-sustainability. China economy has entered into a stage when pattern transition becomes a must. The rather extensive mode must switch to more scientific counterpart; the impetus of growth must be shifted from investment and export to domestic consumption and innovation while environment and ecology are protected more carefully. Since the 10th FYP periods, primary energy consumption increased by 2.2 times and reached up to 3.25 Btce in 2010, accounting for more than 20% of world energy consumption. Meanwhile GHG emissions in China ranked first in the world, accounting 25% of global emission, while the economy scale is only less than 10% of Gross World Product.

China is heavy dependent on coal and annual crude coal production already exceeded 3 billion ton, among which more than half cannot meet with the requirement of international standards in work safety, environment protection and ecology. In this sense, considering environment and ecology constraints, there is little space for the production capacity of coal to increase. GDP is still expected to growth in a high speed and requires even enormous energy supply. To realize sustainable development, energy efficiency, low carbonization and diversity of energy supply will be the main features of energy perspective in China. According to various sources, China's primary energy demand and supply scenario into is compiled and given in Table 8. It is worth noticing that the data in the table is not a prediction with careful calculation, but rather a rough estimation based on satisfaction of reasonable demand with scientific supply capacity.

According to the estimation in Table 8 and the production capacity, around 4 Btce of primary energy consumption in 2015 is a reasonable control goal. Supposed that GDP grow at a speed of 8% annually and a total of 16% reduction in GDP energy intensity was realized during the 12th FYP periods, the primary energy consumption in 2015 would be 4 Btce. Table 9 gives the possible combination of target decomposition for 12th and 13th FYP for realizing 45% reduction in GDP carbon intensity given that 20% reduction in GDP energy intensity was realized during 11th FYP periods. According to Table 9, if 16% reduction was realized during 12th FYP then it would be not so difficult to realize another 10.55% reduction in the 13th FYP. In this sense, a 16% reduction in energy intensity during the periods is rather reasonable and leaves much space for 13th FYP periods. However, if GDP grow at a faster speed of 9% (which is highly likely considering the 11.2% growth rate for 11th FYP periods), a more aggressive goal of 19% EC should be realized to control the primary energy consumption around 4 Btce. To summarize, though the 16% target for 12th FYP is rather reasonable, considering the possible high GDP growth rate and not 100% accomplishment of the 11th FYP goal, another ambitious target (around 20%) may be necessary to leave space for cap control of fossil energy consumption.

4.2. Roadmap of China's energy development into 2050

To safeguard energy demand with more clean and diversified supply, hydropower should be the first and foremost emphasis in China before 2030. Because of the definition of resource endowment and the maturity of the technology, on policy aspect, a more vigorous, rapid and organized plan should be drafted to develop hydropower with ecology protection taking into careful consideration. In that way, the installation of hydropower plant capacity could amount to 300, 400 and 450 GW in 2020, 2030 and 2050 respectively.

Renewable energy other than hydropower should be energetically developed according to local conditions around China. There is vast potential of solar power in 2000 GW, wind power in 1000 GW and biomass energy in 300 Mtce. Before 2020 the focus should be on the innovation of core competency and the breakthrough of bottleneck in technological economics and highlight the economic performance of wind power, cost reduction of solar photovoltaic and photo-thermal generation, grid-access of intermittent power and R&D on cellulose liquid fuel technology, etc. to realize commercialization. The total contribution of renewable energy other than hydropower should reach around 200, 400 and 800 Mtce respectively in 2020, 2030 and 2050, with its strategic position being enhanced as alternate even dominate energy resource, instead of the current complementary role.

Development of nuclear power should be the long term strategic choice for China. With the joint efforts of domestic production and import, uranium resource is no longer the fundamentally restraining factor while safety and cleanliness of nuclear power can also be guaranteed.[1] Following a route chart of "pressurized water reactor-fast reactor-fusion reactor", nuclear power can realize long term sustainable development in China. In 2020, capacity of nuclear power plant can amount to 70 GW and together with renewable energy account for 15% of primary energy consumption. In 2030 nuclear power can amount to 200 GW and in 2050 further to 400 GW. At that time, nuclear power will account for 15% of primary energy consumption and be among the dominating energy sources.

Almost most of the new energy development will be in power sector, so electrification level will increase gradually during China's industrialization and urbanization process. Meanwhile, the ratio of non-fossil power will increase while that of coal power plant will decrease to about 35% in 2050. Power Grid should be smartly planned and designed with the development of power sector, especially the quick growth of renewable energy generation. In this respective, a power grid system that can economically accept and transmit renewable power from the supply-side and encourage energy saving on the demand-side is a priority in China. Hu et al. [27], Yuan and Hu [19] study low carbon power development in China and identify such a power system as Super Smart Grid (SSG). SSG can be combined with Integrated Resource Strategic Planning to identify the costs and benefits of the following practices: (1) promote clean energy use to reduce fossil energy consumption; (2) improve generation efficiency and energy use efficiency to reduce coal consumption; (3) enhance transmission efficiency of the grid to reduce electricity line losses; and (4) improve end use energy efficiency to promote the use of Efficient Power Plants. Interested readers may refer to Yuan and Hu [19] for details of the main components of developing SSG in China.

5. Lessons and discussions

5.1. Discordance between EC goal and development pattern

Though China has achieved miracle of economic growth for more than three decades, the quality of growth has always been criticized. Low final consumption ratio as well as high investment ratio results in the dominance of secondary sector, especially the heavy industry (refer to Fig. 4 for change in GDP sector composition and Table 10 for difference on growth rate for GDP, secondary industry and heavy industry). If China is serious about its new "*scientific development perspective*", it must transform the pattern from investment driven to expenditure drawn, from manufacturing to service, from reliance on resource input to innovation and human capital.

The unsustainable economic pattern poses serious threat to security of energy supply in China. According to estimate, even if the product energy consumption decreased by 68% in 2030 as of 2005, energy intensity would be still one time higher than that in Japan and Europe and at that time China would find impossible to manage energy balance. The implication is that China must focus on the quality, instead of the speed of growth in the future. Central Government has stipulated a rather conservative but balanced goal of 7% GDP growth for the 12th FYP periods. However, according to the publicly accessible development plan of provincial governments, for year 2011, only five provinces (Beijing, Shanghai, Hebei, Zhejiang and Guangdong) formulated growth goal less than 10%

[1] The serious nuclear accident happened in Japan will definitely exert long term impact on world-wide perspective on nuclear power. But considering the immense power demand in the future, China will continue to implement the active plan developing nuclear power.

Table 8
China's primary energy demand and supply scenario into 2050.

Year	Primary energy demand	Coal	Oil and gas (including coal-bed methane)	Nuclear power	Hydropower	*Unit*: Btce Renewable energy other than hydropower
2020	4.0–4.2	2.2–2.4	1.15	0.17	0.3	0.2
2030	4.5–4.6	2.0–2.1	1.3	0.45	0.4	0.4
2050	5.5–5.6	1.8–1.9	1.5	0.9	0.5	0.5

Table 9
Feasibility analysis on 2020 GDP energy intensity goal.

	11th FYP	12th FYP	13th FYP
20% reduction in GDP energy intensity during 11th FYP vs. 45% reduction in GDP carbon intensity in 2020	20%	15%	11.6%
	20%	16%	10.55%
	20%	17%	9.47%
	20%	18%	8.37%
	20%	19%	7.23%
	20%	20%	6.08%

Note: The shading row represents that under the proposed 16% reduction target for 12th FYP, the target remaining for 13th FYP is 10.55% to realize the 2020 45% target.

and all the rest are between 12% and 13%. If unchecked, this trend would ultimately lead to overcapacity in heavy industry.

Table 11 lists the comparison of production for several key energy-intensive products in China for 2000 and 2008. It is estimated that with the production in 2009, 2.5–3.0 billion square meters construction area, 100 thousand km roads, 7 thousand km expressways, 6 thousand km railways, 1500 km high-speed railways and 20 new airports could be built in China annually, which implies that energy-extensive sectors in China has already entered into maturation period and their capacities are beyond the reasonable demand. Anyway, under the current government structure and the division of authority and finance between Central and provincial government, the local government is still tempt to develop heavy industry to boost their revenue. If Central Government is serious on the EC policy, it must shift the incentive structure and put EC and ER target as the priority in local governments' agenda.

5.2. *Deficiency in institution design*

It is widely recognized that energy regulation in China is confusing, suffering in many instances from a lack of clarity in the assignment of responsibility. Prior to the government reorganization announced in March 2008, there was much speculation about the establishment of a Ministry of Energy [20–22]. However, the reorganization did not create such a ministry. Instead a high-ranking Energy Bureau (EB), with a minister as leader, was established under the management of NDRC. The main duties of EB are to propose national energy developing strategy, planning and policies; implement the management of oil, gas, coal and electricity; manage national oil reserve; propose favorable policies for renewable energies and energy conservation; and implement international energy cooperation. However, the division over energy management is still in disorder. One crucial example is the responsibility over energy prices. For electricity, the two energy agencies that could have control over prices are the Energy Bureau or State Electricity Regulatory Commission (SERC). Even though SERC is in charge of electricity market regulation, the most significant tools of market regulation, price regulation is not in its responsibility. Though EB is in charge of energy strategy and energy management, it is not empowered with energy price management. Meanwhile, because it is affiliated to NDRC, its independence to work out energy policy has been questioned ever since its establishment. The authority over electricity as well as oil and gas prices continues to reside in the pricing bureau of NDRC because of the significance of these prices to the overall economy. But NDRC need to consult with EB (and SERC) for energy (if electricity) price policies. Another example is the responsibility over energy efficiency. According to the latest government reorganization, energy conservation is subject to the authority of EB. However, the monitoring and management of enterprises energy consumption is the duty of Ministry of Industry and Information Technology (MIIT). The implication is that, EB has to coordinate with MIIT for issues related with energy efficiency and conservation. In fact, such kinds of inter-ministry coordination are so frequent and difficult that the mechanism of NELG set up in 2005 can no longer cope with them. Then in 2010, Energy Commission headed by Premier Wen Jiabao was set up. It is largely the updating of the NELG, with ministers in charge of related ministries as the commission members, and its main duty is to function as a top-rank negotiation body for energy strategy decision and coordination [23]. Many people argued that this kind of duplicate energy management cannot unify laws and regulations affecting energy related issues and a unified Energy Ministry is needed. The fight over authority even influences the formulation of energy law. Such a law was drafted and widely circulated in December 2007. However, its adoption has been delayed as Government attempts to sort out the authority of EB, Energy Commission, NDRC, SERC, the large and powerful energy companies, and other entities (Table 12).

5.3. *Lack of systematic policy implementation*

Though China has determined to take the "*scientific development perspective*" as its topmost long-term tenet, there is serious deficiency on short range practice. First of all, from central to levels of local governments, the societal and economic development plan should coordinate the balance among economic growth, energy consumption, environment and ecology preservation seriously. Worship of GDP should be revolutionized in governments' plans. Especially, Regional Function Plan has been formulated and approved by the State Council in December of 2009.[2] The idea underlying the plan is to classify different regions into four catalogues according to three criteria: resource and environment carrying capacity, current exploration intensity and future exploration potential. The four catalogues are classified as development

[2] Xinhua News Agency. Regional Function Planning approved by the State Council. 13th, June, 2010.

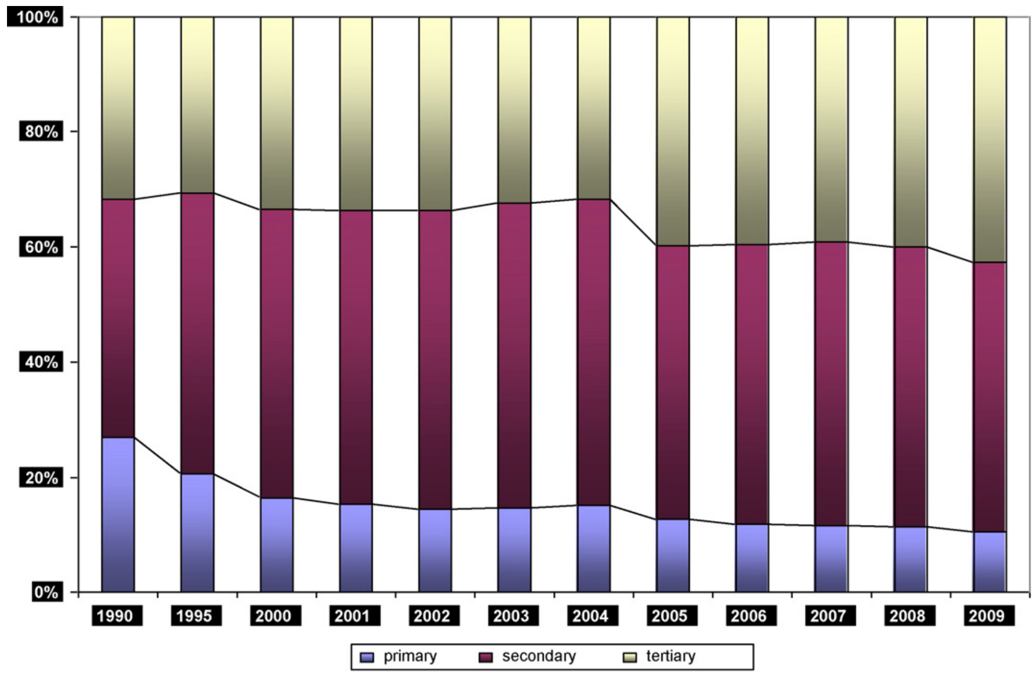

Fig. 4. GDP sector compositions for selective years.

Source: NBS China Statistics book, various years.

Table 10
Comparison of GDP, secondary sector and heavy industry growth rate during 2005–2009.

	2005	2006	2007	2008	2009	2010
GDP	10.40%	11.60%	13.00%	9.00%	9.10%	10.3%
Secondary sector	11.40%	12.50%	13.40%	9.30%	9.50%	12.2%
Heavy industry	17.00%	17.90%	19.60%	13.20%	11.50%	16.5%

Source: NBS annual statistical communiqué 2006–2011.

Table 11
comparison of production for several energy-extensive products in China for 2000 and 2008.

Units: 10 thousands ton	2000			2008		
Selective energy-extensive product	China	World	China vs. World (%)	China	World	China vs. World (%)
Crude steel	12,770	57,009	22.4	56,900	120,000	47
Steel material	14,121	92,947	47	69,600	140,000	50
Cement	59,700	175,588	34	163,000	300,000	54
Sodium hydroxide	648	4500	14.4	1718	5866	29.3
Calcined soda	803	3460	23.2	1553	4800	32.4
Ethylene	479	9000	5.3	2431	12,040	20.2

priority zones, development emphasis zones, development limit zones and development prohibition zones. The main differences are their development goal, direction and principles. In the future, the social and economic development plan at all levels should be based on the Regional Function Plan with the implication that GDP growth should no longer be the only goal for many regions. Instead, protection of environment and preserve of ecology system will be the most important tasks for development prohibition zones. With balanced plan, the most important thing in the next step is to formulate scientific government and personnel performance system to correctly guide the behavior of local government.

5.4. *Lack of coordination between market mechanism and government command-and-control*

Until recently, energy efficiency policies in China are largely in the type of command-and-control. 1000 enterprises energy conservation program, phase-out of low efficient production capacity, etc. all belong to this type. The apparent deficiency is the unwillingness on the part of the government to use economic and financial instruments to complement the preferred administrative approach [24]. Energy users see little economic incentive to save energy because energy prices have been tightly constrained. Though reforms on oil and coal recently have fixed the distortion of energy price to a certain extent, their prices are still under the regulation of government while electricity price is subject to strict control. In fact, energy price is the most sensitive part of energy policy. On the one hand, China government wants to control energy price to curb inflation and maintain the living standard of household. On the other hand, obvious distorted price signal cannot demonstrate the determination of Government to pursue its "*scientific development perspective*" to balance economic growth with environment and resource. Anyway, only proper price can signal scarcity of energy and environment supply.

Phase-out of low efficient production capacity has fared well in power industry. It is understandable because power industry

Table 12
Energy-related administrative function division in China before 2008.

Government agencies	Energy-related administrative function
National Development and Reform Commission	Making national energy strategies and policies. Formulating energy development plans. Suggesting reform of relevant energy system. Managing oil, natural gas, coal, electric power. Nuclear, and other energy. Managing national oil reserves. Developing policy measurements for energy conservation and new energy. Energy pricing, and Total energy demand control and approval of large energy projects.
Ministry of Land and Resources	Preparation of mineral resource-related laws, regulations and technological requirements. Managing permits for exploration and mining of oil and natural gas. Managing geological surveys and relevant information. Managing charges and use of mineral resource compensation fees, and Managing oil and natural gas reserves.
Ministry of Housing and Urban–Rural Construction	Feasibility research of construction projects. Managing expenses of engineering and land use of project, and Assessing survey design and construction of oil projects.
Ministry of Commerce	Managing permits and quotes for import/export on crude oil, gas, and oil products. Preparation of operation policies for oil product market. Supervision and control market operation. Assessment of foreign investment enterprises, and Approval of large foreign investment projects.
Ministry of Environmental Protection	Making environmental regulations and policies. Supervision of implementing laws and regulations, and Assessment of environmental impact reports on large energy projects.
Ministry of Water Resources	Managing development of hydro electric power.
Ministry of Agriculture	Managing development of biologic energy resources.
Ministry of Science and Technology	Research and development for new and renewable energy resources and technologies. Research and development of clean and energy-saving technologies and products.
State Administration of Work Safety	Supervising and monitoring energy enterprises to implement laws, regulations, and policies for safety production. Inspection of serious accidents in energy production, and Supervising and coordinating emergency assistance for accidents.
State Administration of Taxation	Collecting and managing the resource taxes for oil, natural gas, and other energy resources. Collecting and managing taxes for use of mining areas or fields.
State Electricity Regulatory Commission	Researching and proposing electricity regulatory law and regulation. Participating in the formulation of state electric power planning. Regulating the operation of power market. Participating in the formulation of power technology, safety and quality standard. Proposing the electricity pricing adjusting suggestion to the ministry in charge of price; supervising the electricity price. Being responsible for the electricity safety supervision.

Source: Revised by the authors based on Yu [41].

is highly concentrated with six big state-owned and dozens of province-owned enterprises (SOEs). Because the managers of SOEs are appointed and appraised by government, Joint efforts by NDRC, EB, NERC, MIIT and SASAC can easily make effect on SOEs. However, energy efficiency policy on numerous small-scale industrial boilers which mostly are owned by private owners is not direct and effective. Though administrative instruments may be effective when applied to a relatively small number of target enterprises or institutions, they are ineffective across the wider economy unless accompanied by suitable economic measures. Phase-out of low efficient capacity in steel industry is such a case. China hoped to restructure the steel industry as early as 2000 to enhance industry concentration and upgrade technology; the industry in China today is still in low concentration with thousands of low efficient small enterprises. On the one hand, those wishing to invest in new equipment or processes cannot easily gain access to finance, and tax incentives are inadequate. On the other hand, those small steel enterprises are still profitable and unwilling to be shut down simply because of cheap environment and energy cost. Someone even argued that such forced policy itself is unreasonable simply because market force should be enough to "phase out" low efficient players in economic sense. If not probably something underlying the market framework is wrong, which should be the policy focus of the Government. Thereby in the long run only a host of coordinated market mechanism, including price, tax, environment standard and regulation, investment and finance policy, hand in hand with command-and-control, can sustain long-term effect.

6. Policy outlook

Sustainable energy development strategy in China can be summarized as "scientific, green and low carbon". The most difficult period to realize energy transition in China is the first 20 years before 2030, during when great efforts should be put into the mechanism design for EC efficiency improvement, the breakthrough in new energy development, clean production and utilization of fossil energy and the curb of pollutant and GHG emissions. Issues of oil supply safety and replacement, optimum development of power sector, significant advance in rural energy, etc. should be tackled properly during the periods.

The first 10 years before 2020, especially the 13th FYP periods, is the strategic window period to accomplish the above

mentioned tasks and realize the transition to the "*scientific development perspective*". Output and energy consumption structure must be adjusted radically to achieve energy saving, efficiency enhancement and emissions reduction and to manage the sustainable balance between energy supply and demand. However because of the system inertia of extensive growth mode, without a strong hand of macro adjustment, it is difficult to implement the energy policy properly. Strong policy mechanism should be employed to promote transition in development pattern by means of reducing energy intensity and controlling fossil energy consumption. We hereby propose policy recommendations as the follows.

Management system on EC and ER should be adjusted radically. The ministry in charge of energy issue should be set up to formulate and implement integral and consistent energy policy. To governments and enterprises in all levels, more scientific performance system should be formulated. Especially, the requirements on energy saving and low carbon development should be taken as mandatory indexes in the performance evaluation system.

The strategy of "saving as a priority and cap control of energy consumption" should be strengthened. During the 11th FYP periods to achieve the GDP energy intensity reduction target, the State Council proposed the decomposition framework. In the 2011 Government Work Report it is firstly proposed to decompose EC target for manufacturing, construction, transportation sectors and public agencies, meanwhile key projects will continue to be implemented. Accordingly, *the 1000 Key Enterprises Special Program* will be extended to ten thousand enterprises and cover all the nine energy-extensive sectors including steel, coal, power, oil refinery, chemical, building material, nonferrous metal, textile and paper and pulp, etc. However, it should be noticed that reducing energy intensity does not necessarily bring forth reduction in energy consumption if the related enterprises manage to lower workload energy consumption but enlarge the production significant by large scale capital investment and replacement. Unfortunately, this is what happened in many energy-intensive enterprises during the past 5 years. Therefore without a cap on energy consumption, it is impossible to achieve the target of EC. On the other hand, these ten thousand key enterprises account for about 60% of industrial energy consumption in China and if some pilot measures were employed important demonstrative effect would sustain. So we propose that when decomposing energy intensity target to these enterprises, the total volume of fossil energy consumption for every enterprise according to proper planning and decomposition procedure should also be set. The mandatory cap then can foster a voluntary trade market for energy consumption quota, which will be more cost-efficient and provide valuable experience for the management of more sophisticated carbon market.

More market-oriented economic policies should be implemented to mobilize the inherent motive of local governments and enterprises on energy saving. The legislations on energy, including resource tax, pollutant emission tax, carbon tax, energy pricing mechanism, product technology standard and energy efficiency standard, etc. should be drafted or reformulated to systematically curb the overcapacity of energy-intensive industries, guide the development of low-carbon or carbon-free buildings and vehicles and move toward service-centered economy.

Some important energy policies should be implemented as early as possible. Following are some priorities: promote the intensive production of coal and increase the application of coal washing; regain examination and approval of hydropower projects; speed up the construction of inland nuclear power plant with available technology; build up the policy and management system for developing natural gas; invest significantly in renewable energy R&D and break the bottleneck limiting its rapid development; carry out systematic power optimization including both generation capacity and grid framework.

Build up national level energy science R&D platform and speed breakthrough on key energy fields. Increase technology R&D input, especially on clean coal, high efficient energy utilization, advanced power generation, next generation nuclear power, etc. and stipulate detailed development roadmap for them. A special fund to develop new energy technology should be established to support technology R&D and demonstration projects for breakthrough in technological-economics bottleneck, education of talents and enhancement of core competency.

Encourage green consumption and new ecology civilization in the whole society. Resource, ecology and environment capacity should be taken as the restricting factors of economic activity. Governments of all levels should take the initiative to encourage the consumption and living pattern in suite of "healthy material consumption and enriched spiritual pursue" adapted to China condition. Change in consumption behavior and life style is, though rather difficult, the ultimate solution to sustainable development.

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